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# DETERMINATION OF THE ABSORPTION PARAMETERS OF SOME MATERIALS FOR PHOTON ENERGIES WITH NAI (TL) DETECTOR

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## ABSTRACT

Shielding of gamma radiation primarily involves the interaction of gamma radiation with matter. In this measurements have been made to determine the absorption parameters of Carbon, Copper and lead elemental materials of gamma-rays photons from $^{22}$Na, $^{137}$Cs and $^{60}$Co sources using the NaI (Tl) detector. The attenuation in the intensity of the beam will be determined for each varying thickness of absorber materials. Absorption properties were interpreted by means of the linear attenuation coefficient μ, mass attenuation coefficient $\mu_m$, half-value layer thickness and ten value layer thickness. Among these the mass absorption coefficients is the most specific parameter because it can be specified only by gamma ray energy.

**KEYWORDS**: NaI (Tl) detector, shielding, absorption parameters, mass attenuation coefficient, linear attenuation coefficient, half-value layer thickness and ten-value layer thickness.

## 1. INTRODUCTION

The study of interaction of nuclear radiations with matter is the important research area for the development of materials which can be used in high radiation environmental. When the attenuation of a collimated beam of gamma radiation passing through matter is considered the total absorption coefficient is used. Since a scattering collision, between a photon and an electron, reduced the beam intensity just as absorption. The total mass attenuation coefficients μ are provided in the units of ($m^2$/kg) or ($cm^2$/g), because in these unit the density of the materials does not have to be specified. For a compound or mixture, an effective molecular weight is obtained from the equation [2,4].

$$\sqrt{A_{ef}} = \left(\sum_{i=1}^{L} \frac{W_i}{\sqrt{A_i}}\right)$$

Where the quantities $w_i$, $A_i$ and L mean weight fraction of the element, atomic weight of the element and number of elements in the compound or mixture. The data based on mass attenuation coefficient and half value layer are very useful for the purpose to identify the various radiation shielding materials. In the environment of high radiation exposure used as radiation shielding materials. The mass and linear attenuation coefficient, stopping power, half-value layer, built-up factor are basic quantities used in calculations of the penetration and the energy deposition by photons in biological, shielding and other materials[5]. The attenuation coefficient and build-up factor are a few of the important characteristics that need to be studied and determined prior to using a material clinically in radiation treatment and protection. The attenuation in the intensity of the beam will be determined for each varying thickness of absorber materials. Plotting the thickness of the absorber materials versus the corresponding intensity of the beam will allow calculation of the linear attenuation coefficient [7].

## 2. THEORY

The interaction of gamma rays with matter is characterized by the fact that gamma ray photon is removed individually from the incident in a single event. When gamma radiation is incident on metal surface in finite thickness of material there exists some probability that the radiation will interact in the material can be attenuated. One of the most important quantity, characterizing the penetration in a medium is the attenuation. The term "attenuation" refers to the remaining photons that have either been absorbed or scattered in the layer.In the gamma attenuation there are narrow beam attenuation and broad beam attenuation. For narrow beam, so called good geometry conditions, the necessary shielding thickness can be calculated by the following exponential absorption equation [4,6].

$I = I_0 \exp(-\mu t)$

The linear attenuation coefficient μ it can be represent combine coefficient of all interaction mechanism for the photon and, the linear attenuation coefficient is the sum of the coefficients of photoelectric effect, Compton scattering and pair production. It depends on Z of the materials [2].

$\mu = \tau\ (\text{Photoelectric}) + \sigma\ (\text{Compton}) + K\ (\text{Pair})$

The mass attenuation coefficient is the ratio of linear ttenuation coefficient to the density of compound materials, it can be calculated the following equation [4].

$$(\frac{\mu}{\rho})_C = \sum_i W_i\, (\frac{\mu}{\rho})_i$$

Where, $w_i$ is weight fraction of element i in the compound or mixture. It is often used in $cm^2/g$.

***Linear Attenuation coefficient***

The linear attenuation coefficient describes the fraction of a beam of x-rays or gamma rays that is absorbed or scattered per unit thickness of the absorber. This value basically accounts for the number of atoms in a cubic cm volume of material and the probability of a photon being scattered or absorbed from the nucleus or an electron of one of these atoms [4].The value of linear attenuation coefficient is given by equation (1).

$$\mu = \frac{1}{t}\ln\frac{I_0}{I} \quad \text{.................. (1)}$$

***Mass attenuation coefficient***

Since a linear attenuation coefficient is dependent on the density of a material, the mass attenuation coefficient is often reported for convenience. Consider water for example. The linear attenuation for water vapor is much lower than it is for ice because the molecules are more spread out in vapor so the chance of a photon encounter with a water particle is less. Normalizing linear attenuation coefficient by dividing it by the density of the element or compound will produce a value that is constant for a particular element or compound. This constant ($\mu_m$) is known as the mass attenuation coefficient and has units of $cm^2/g$ [4].

Mass attenuation coefficient or mass narrow beam attenuation coefficient of the volume of a material characterizes how easily it can be penetrated by a beam of light, sound, particles, or other energy or matter and it can be calculate the following [10]. The value of mass attenuation coefficient is given by equation (2).

$$\mu_m = \frac{\mu}{\rho_m} \quad \text{..................... (2)}$$

***The Half Value Layer and Ten Value Layer thickness***

The HVL and TVL are defined as the thickness of a shield or an absorber that reduces the radiation level by a factor of one-half and one tenth of the initial level respectively and they can be defined in terms of the effectiveness of gamma ray shielding [1].The concept of HVL and TVL is very useful in approximate shielding calculations. The values of HVL and TVL thicknesses are given by equation (3) and (4).

$$\text{HVL} = \frac{\ln 2}{\mu} \quad \text{..................... (3)}$$

$$\text{TVL} = \frac{\ln 10}{\mu} \quad \text{..................... (4)}$$

**Experimental ascept**

First of all the counting system should be calibrated and the working voltage of NaI (Tl) detector was determined practically at 650V. The slabs samples of various thickness were placed in the path of the beam of the gamma rays, from radioactive sources, and the detector was respond and record on the MCA. The intensity of gamma-radiation decreases when it passes through solid matter.

Scintillation detectors compose of a scintillator material and photomultiplier tube connected to materials. When ionizing radiation interact with the scintillation materials, it can cause ionization or excitation. Scintillation light emitted by the phosphor was collected by photomultiplier tubes, it is converted to voltage pulse. The obtained of the pulse amplitude is proportional to the energy of the radiation. These detectors can also be used for counting and energy discrimination. An iodine has high atomic number in NaI crystal, it can be obtained high detection

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efficiency. Usually a small amount of thallium is added to crystal in order to activate and this new structure is called NaI (TI). It can be seen from fig (1) and 2 x 2 NaI (Tl) detector is shown.

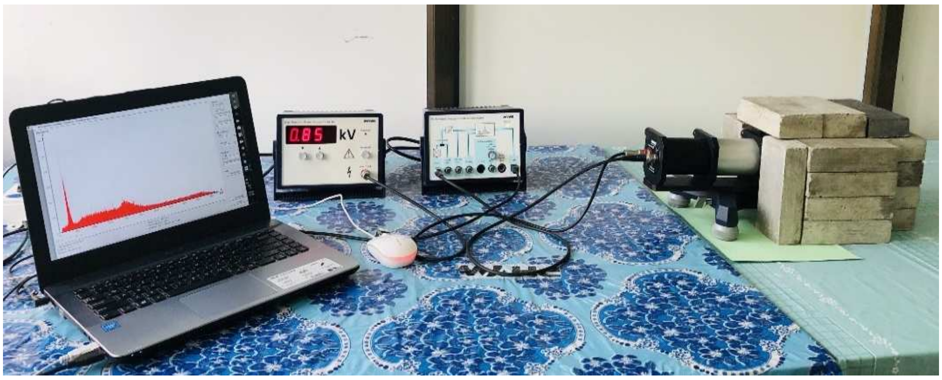


***Fig. 1. Laboratory equipment for measure of gamma radiation spectrum with the Scintillation counter***

The detector was placed horizonally and the distance between source and detector was 6cm. In this case the gamma sources are $^{60}Co$, $^{137}Cs$ and $^{22}Na$ the radiation of interest is gamma. Although, the radiation transferring medium is air, it can not be attenuate the gamma ray intensity and energy within these ranges.

## 3. RESULTS AND DISCUSSION

In this study energy calibration of NaI (Tl) detector has been done using $^{22}Na$, $^{137}Cs$ and $^{60}Co$ gamma ray sources. Fig (2) is shown the energy calibration curve for various four energise. The different nuclear parameters of sources are given in table (1). The efficiency for different energies in the air and constant source to detector distance, the efficiency decreases with increasing energy and for high energy the efficiency is approximately constant (from 800 keV). Efficiency was highest for $^{22}Na$ (Eγ =511 keV) and lowest for $^{60}Co$ (Eγ =1332 keV). i.e. the detector is more effective for the lower energies. Fig (3) is the absolute efficiency curve for energy range 511keV to 1332keV.

The measured gamm ray spectra of Na, Cs and Co are shown in fig (4, 5, and 6). The measure spectra clearly indicated two well separated photo peaks without absorber and with absorber corresponding to the gamma energies. The linear attenuation coefficients for four different energies have been obtained using gamma spectrometer. The mass and linear attenuation coefficients for four different energies have been obtained using gamma spectrometer and the calculated data for three absorbers are shown in table 2.

***Table1. Nuclear parameters for standard gamma ray sources***

| Sr. no. | Gamma source | Gamma energy (keV) | Initial activity (Bq) | Half life (years) | Density (g/cm$^3$) |
|---|---|---|---|---|---|
| 1 | $^{60}Co$ | 1173 | 37000 | 5.3 | 8.96 |
| | | 1332 | | | |
| 2 | $^{22}Na$ | 511 | 185000 | 2.6 | 11.3 |
| 3 | $^{137}Cs$ | 662 | 185000 | 30.1 | 2.05 |

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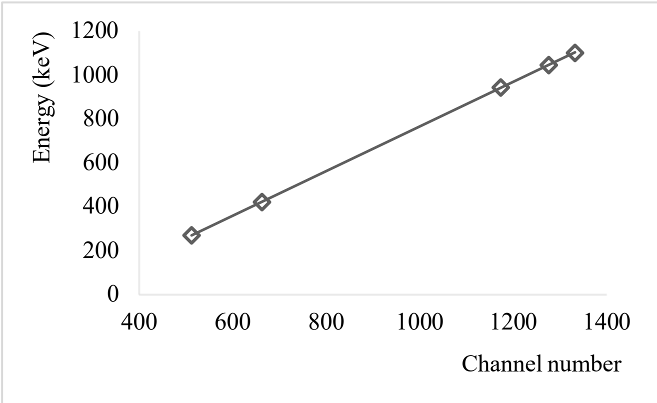


***Fig. 2. Energy Calibration Curve for energy range511keV to 1332keV***

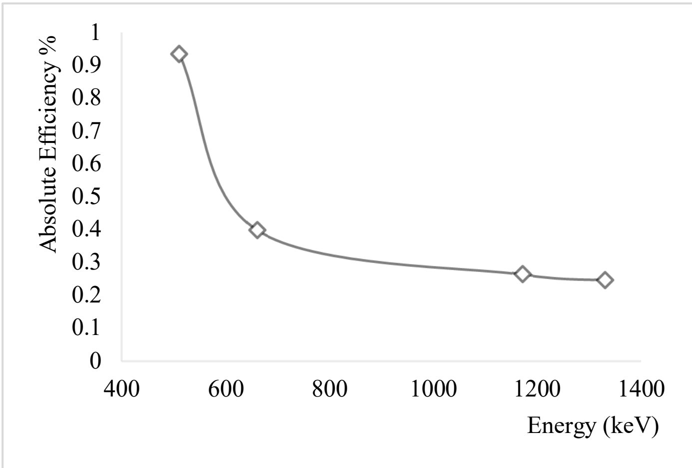


***Fig. 3. Absolute Efficiency Curve for energy range 511keV to 1332keV***

Tables and graphs to show the effect of varying the thickness of lead, copper and carbon absorbers on the gamma counts for different energies sources. The results of the linear and mass attenuation coefficients as a function of gamma ray energies are displayed in Figure 7 (a) and (b).

Calculated HVL and TVL values for different densities of absorbers are shown in table (3) and in fig (8) for four values of different gamma-ray energies. It is clearly seen from fig (9, 10 and 11) are shown the linear attenuation coefficient increases with the increasing density of the absorbers and when attenuation coefficient increases, the HVL and TVL values decrease for corresponding gamma energies.

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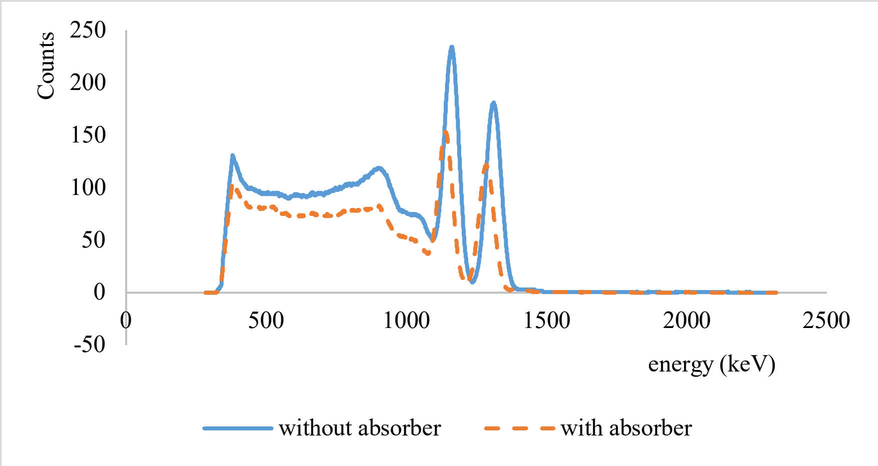


***Fig. 4. The measure gamma ray spectra of Co-60 without absorber and with absorber***

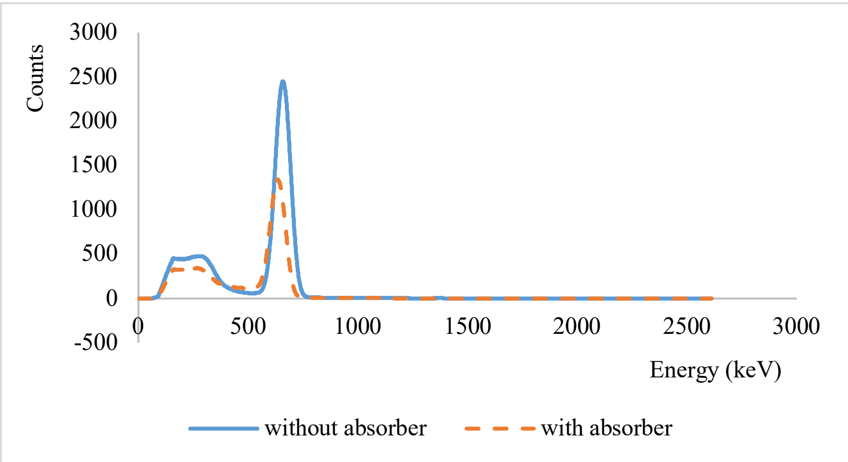


***Fig. 5. The measure gamma ray spectra of Cs-137 without absorber and with absorber***

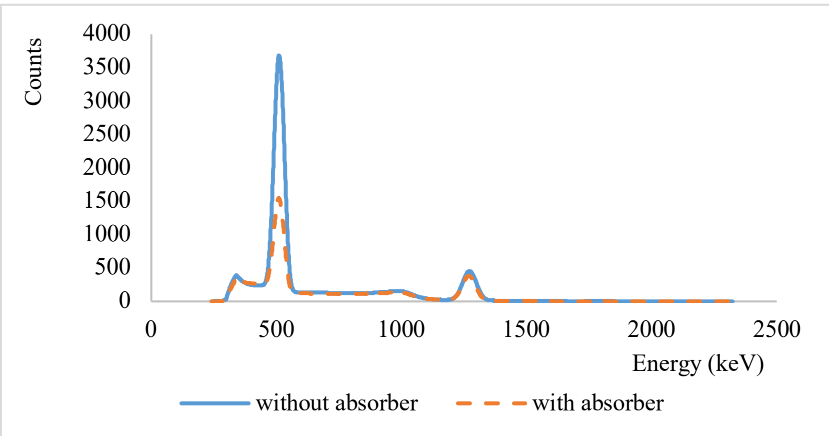


***Fig. 6. The measure gamma ray spectra of Na-22 without absorber and with absorber***

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***Table 2. Calculated data of absorption coefficients for three absorbers***

| Energy (keV) | Copper | | Carbon | | Lead | |
|---|---|---|---|---|---|---|
| | □□□cm$^{-1}$) | □$_m$ (cm$^2$/g) | □□□cm$^{-1}$) | □$_m$ (cm$^2$/g) | □□□cm$^{-1}$) | □$_m$ (cm$^2$/g) |
| 511 | 0.68340452 | 0.07627283 | 0.1515966 | 0.07395 | 1.5112 | 0.133734 |
| 662 | 0.54809123 | 0.0611709 | 0.1293342 | 0.06309 | 1.187679 | 0.105104 |
| 1173 | 0.45104939 | 0.05034033 | 0.10749 | 0.052434 | 0.768304 | 0.067991 |
| 1332 | 0.4173974 | 0.04658453 | 0.1022184 | 0.049863 | 0.675312 | 0.059762 |

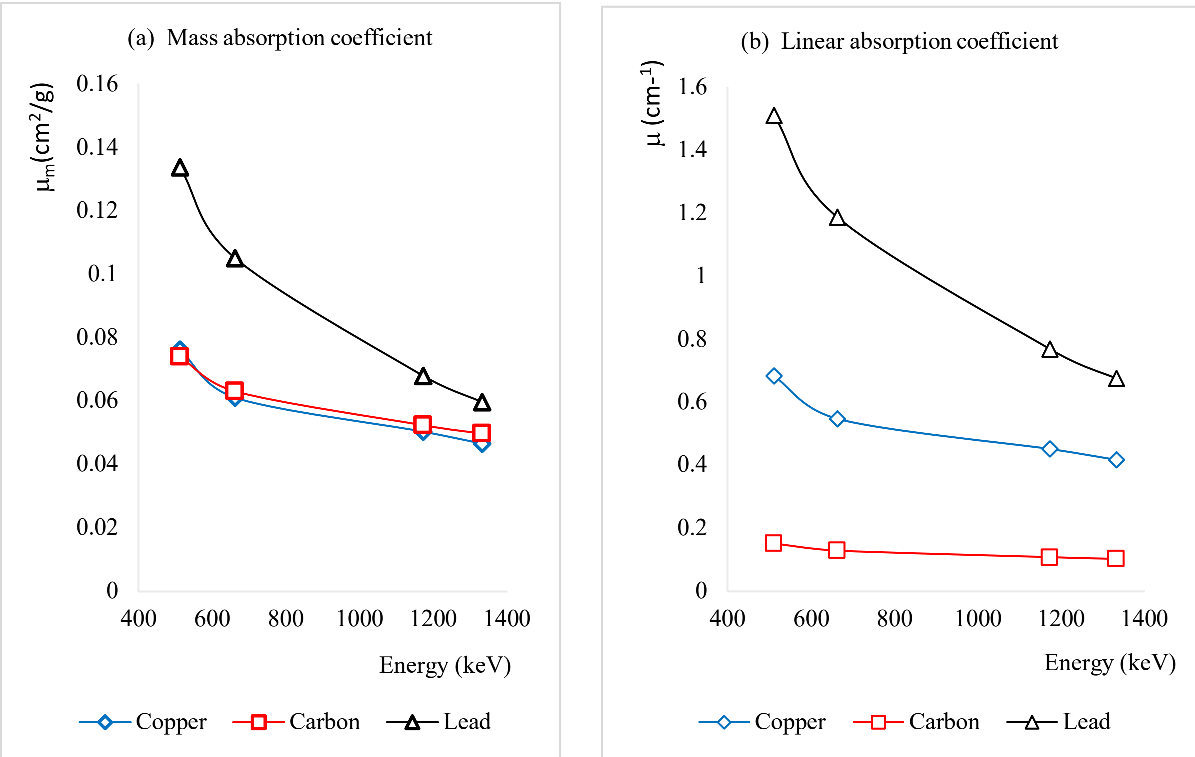


***Fig. 7. (a) The results of the mass attenuation coefficients with respect to gamma ray energies***
***(b) The results of the linear attenuation coefficients with respect to gamma ray energies***

***Table 3: Calculated data of HVL and TVL thickness for C, Cu and Pb.***

| Energy (keV) | Carbon | | Copper | | Lead | |
|---|---|---|---|---|---|---|
| | HVL (cm) | TVL (cm) | HVL (cm) | TVL (cm) | HVL (cm) | TVL (cm) |
| 511 | 7.36225908 | 15.3924544 | 1.0881941 | 3.61567 | 0.513123 | 1.704919 |
| 662 | 8.66256146 | 18.7530926 | 1.3338083 | 4.431756 | 0.58444 | 1.941881 |
| 1173 | 11.2248973 | 22.1604693 | 1.5422861 | 5.124452 | 0.927125 | 3.080496 |
| 1332 | 11.2062227 | 22.5373821 | 1.6622344 | 5.522996 | 1.087047 | 3.61186 |

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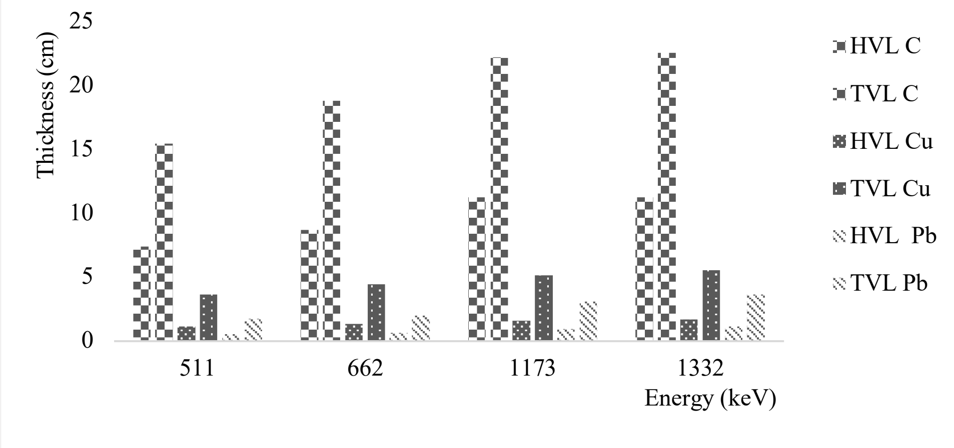


***Fig.8. HVL and TVL thickness of three absorber materials for four different energies***

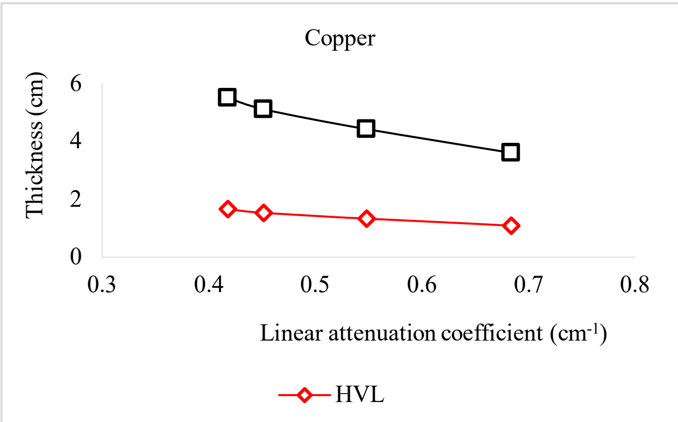


***Fig.9. Relation of HVL and TVL with $\mu$ for copper absorber***

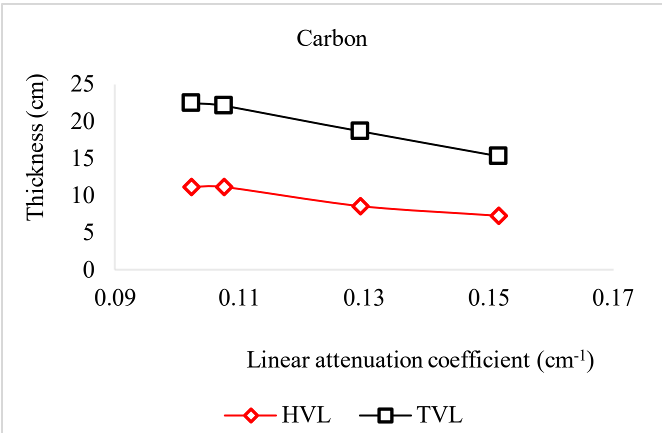


***Fig.10. Relation of HVL and TVL with $\mu$ for carbon absorber***

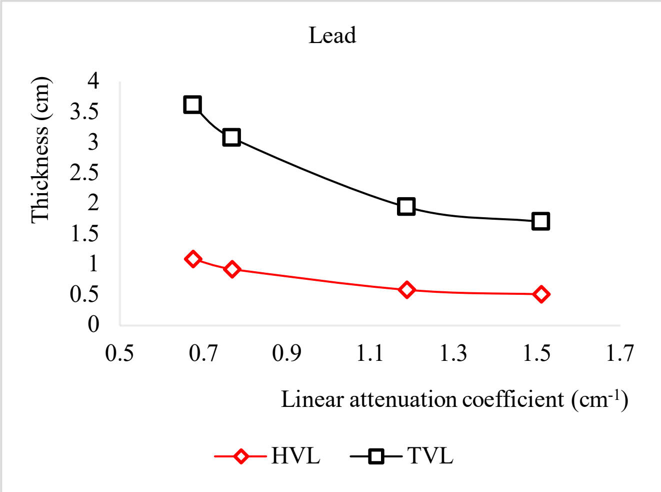


***Fig.11. Relation of HVL and TVL with μ for lead absorber***

## 4. CONCLUSION

The absorption parameters for three elemental materials C, Cu and Pb were measured in the gamma energy range from 511 keV to 1333 keV using a NaI (Tl) scintillation detector. Mass attenuation coefficients for the elements at incident energies are determined by the transmission for collimated mono-energetic beam. The experimental mass attenuation coefficients for almost all samples are nearly agreement theoretical values measured by Seltzer (1995) for corresponding energies [8]. In the measured and theoretical values are observed for low energies especially in the cases where carbon and copper were considered as absorbers. The radiation shielding calculations, HVL and TVL values are also important things. It can be concluded from this work, that HVL and TVL values for three absorbers with different densities were calculated for energies from 511 keV to 1332 keV. From experimental result the increasing density of the absorbers, the HVL and TVL values decrease. It is shown that the photon energy can be minimized by increasing shielding material density, but also the reducing the materials HVL and TVL thickness.

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